STUDIES ON THE ECONOMIC BIOLOGY OF THE SAND WHITING (*SILLAGO CILIATA* C. & V.).*

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(Four Text-figures.)

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I. Introduction.

The term "whiting" is a vernacular title and refers, in Australian waters, to the teleostean family Sillaginidae. The sand whiting of New South Wales and Queensland is the species *Sillago ciliata* (Cuvier and Valenciennes, 1829).

The Australian whitings comprise some four species of economic importance and are distributed along the east and south coasts of the continent. The species involved are: the sand whiting (*Sillago ciliata* C. & V.), the bass whiting (*S. bassensis* C. & V.), the trumpeter whiting (*S. maculata* Q. & G.), and the spotted whiting (*Sillaginodes punctatus* (C. & V.) Gill).

With the exception of the South Australian spotted whiting fishery, the whiting fisheries are of only minor economic importance, as Table 2 indicates.

The present paper is a technological discussion of the sand whiting fishery, and while incomplete, it is felt that it provides the basis for a rational control of the fishery.

Several abbreviations have been employed:

L.C.F. denotes length from the tip of the snout to the caudal fork, a measurement accurately and easily made. All lengths, unless otherwise stated, are L.C.F.'s. For conversion of L.C.F. to total lengths Table 1 is appended.

S.E. denotes standard error.

S.D. denotes standard deviation.

C.V. denotes coefficient of variation.

Sample Mean is the mean of the means of individual samples.

Single Sample denotes the characteristics of a sample of fish collected at one point in space and time.

L1, 2, 3, etc., represent the intermediate lengths as calculated from the rings on the scales.

The work embodied in this paper was carried out during 1942–44.

Table 1.

Conversion of L.C.F. to Total Lengths.

Length to caudal fork	150	170	190	210	230	250	270	290
To find the total length, add x mm. to L.C.F.	10	11	12	14	15	16	18	19

Unless otherwise stated, all conclusions, figures and tables refer to both Queensland and New South Wales populations.

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TABLE 2.

Whiting Catches in the Various States.

	S. Aust.*	Qld.†	N.S.W.‡	Vict.**
Weight, lb./year	2,100,000	448,000	438,000	160,000
Per cent. total onshore fish	60	9·6	2·7	6·5
Per cent. Australian whiting	67	14	14	5
Approx. annual value	£150,000	£25,000	£25,000	£9,000
Main species	*S. punct.*	*S. cil.*	*S. cil.*	*S. bass.*
Period	1936–42	1936–42	1938–42	1911–41

C.V. of catch statistics, between years, is about 15%.

* South Australia, Department of Fisheries and Game, Reports, 1936–44.

†Queensland Fish Board, Annual Reports, 1 et seq.

‡ Manuscript Reports by the New South Wales Fisheries Department field inspectors, 1938–1944.

** Manuscript records of fish arriving at Melbourne Markets, 1911–1944.

II. TAXONOMY.

Genus SILLAGO Cuvier.

Sillago Cuvier 1817, *Reg. Anim.*, 2, p. 258; Swainson 1839, *Nat. Hist. Anim.*, 2, p. 205; Gill 1861, *Proc. Acad. Nat. Sci. Philad.*, p. 504; Boulenger 1910, *Ann. Nat. Hist.*, 8, p. 269.

SILLAGO CILIATA Cuvier and Valenciennes.

Cuvier and Valenciennes 1829, *Nat. Hist. Poiss.*, 3, p. 415; Gunther 1860, *Cat. Fish. Brit. Mus.*, 2, p. 245; Gill 1861, *Proc. Acad. Nat. Sci. Philad.*, p. 504; Jonan 1861, *Soc. Cherbourg. Mem.*, 8, p. 272; Steindachner 1866, *Sitz. Acad. Wiss. Wien.*, 53, p. 443; Kner 1869, *Reise. Novara. Fische*, p. 127; Castlenau 1873, *Proc. Zool. Soc. Vict.*, 2, p. 113; 1875, *Off. Rec. Philad. Cent. Exhib.*, p. 16; 1876, *Res. Fish Aust.*, p. 16; Alleyne and Macleay 1877, PROC. LINN. SOC. N.S.W., 1, p. 279; Klunzinger 1879, *Sitz. Acad. Wiss. Wien.*, 80, p. 369; Schmelz 1879, *Cat. Mus. Godeffroy*, 7, p. 44; Gunther 1880, *Chall. Exp. Reps.*, 1, p. 42; Macleay 1881, PROC. LINN. SOC. N.S.W., 5, p. 567; 1881, *Desc. Cat. Aust. Fish.*, 1, p. 42; Woods 1882, *Fish. N.S.W.*, p. 65; Pohl 1884, *Cat. Mus. Godeffroy*, 9, p. 32; Ogilby 1886, *Cat. Fish. N.S.W.*, p. 31; Kent 1889, *Food Fish. Qld.*, p. 11; McCoy 1889, *Prod. Zool. Vict.*, 2, p. 299; Cohen 1892, *Mar. Fish and Fisheries, N.S.W.*, p. 16; Kent 1893, *Gt. Barrier Reef*, p. 293; Ogilby 1893, *Fish. N.S.W.*, p. 63; Waite 1901, *Rec. Aust. Mus.*, 4, p. 47; 1904, *Mem. N.S.W. Nat. Club*, 2, p. 31; Jordan and Seale 1905, *Bull. U.S. Bur. Fish.*, 25, p. 277; Stead 1906, *Fish Aust.*, p. 109; 1908, *Fish. N.S.W.*, p. 63; McCulloch 1911, *Endeavour Zool. Res.*, 1, p. 62; Roughley 1916, *Fish Aust.*, p. 90; Ogilby 1920, *Comm. Fish. Fisher. Qld.*; McCulloch 1927, *Fish. N.S.W.*, p. 50; Fowler 1928, *Mem. Bishop Mus.*, 10, p. 235; Weber and De Beaufort 1931, *Fish. Indo-Aust. Archip.*, 6, p. 178; Fowler 1933, *Bull. U.S. Nat. Mus.*, 100 (12), p. 428. SILLAGO CILIATA DIADOI: Whitley 1932, *Rec. Aust. Mus.*, 18, p. 344. SILLAGO BASSENSIS: Castlenau 1879, PROC. LINN. SOC. N.S.W., 3, p. 381; Macleay 1881, *Ibid.*, 5, p. 567; Kent 1893, *Gt. Barrier Reef*, p. 291; Tosh 1903, *Proc. Roy. Soc. Qld.*, 17, p. 175. SILLAGO DIADOI: Tholliere 1856, *Ann. Soc. Imp. Agric. Hist. Nat. Lyons*, 8, p. 351; Tholliere 1857, *Fauna Woodlark*, p. 151. SILLAGO GRACILIS: Whitley 1932, *Gt. Barrier Reef Exp.* 4, No. 9. SILLAGO INSULARIS: Castlenau 1873, *Proc. Zool. Soc. Vict.*, 2, p. 113. SILLAGO TERRAE-REGINAE: Castlenau 1873, PROC. LINN. SOC. N.S.W., 2, p. 232.

No attempt will be made here to give a full taxonomic description of the fish, but, for rapid identification in the field, the following simple key has been constructed.

1. Spot at base of pectoral fin.
   .1 Slight longitudinal lateral band .... *ciliata* (C. & V.)
   .2 Pronounced band .... *maculata* (Q. & G.)
2. No spot at base of pectoral fin.
   .1 Body with rusty red blotches .... *bassensis* (C. & V.)
   .2 Body without rusty red blotches.
      .21 Anal fin with 20 spines and rays .... *robusta* (Stead)
      .22 Anal fin with 24 spines and rays .... *sihama* (Forskal)

These are the only whitings likely to be found on the east coast of Australia.

III. THE FISHERY.

1. *General.*

The sand whiting is a typical onshore fish occurring in the estuaries, bays, lakes and surf of the east coast of Australia. The normal habitat appears to be the sand flats, and to a lesser extent the mud flats, in water of up to three fathoms deep. Using the catch statistics of New South Wales, and expressing the whiting catch as a percentage of the total fish (less the travelling mullet) caught at the various stations, no difference could be demonstrated in the productivity of bays and lakes as compared with estuaries. The fish appears to congregate about the mouths of estuaries, but may be found for a considerable distance upstream.

2. *Distribution.*

The distribution of fish along the coast of New South Wales was analysed by dividing the coast into ten areas, corresponding to the latitude parallels; these data are summarized in Table 3. Row A shows the percentage which the whiting taken in the area is of the State total whiting landings; row B shows the percentage which the whiting landing makes of the total fish, less travelling mullet, landed in the area, and thus the proportion which the whiting makes of the fish indigenous to the area.

TABLE 3.
Distribution of Sand Whiting along the Coast of New South Wales.

Area	1	2	3	4	5	6	7	8	9	10
A	7·5%	7·6%	11·3%	9·3%	21·9%	21·9%	8·3%	8·3%	2·5%	0·2%
B	7·5%	7·4%	4·8%	8·0%	10·1%	5·6%	5·3%	2·4%	1·4%	0·13%
Latitude ..	28–9	29–30	30–1	31–2	32–3	33–4	34–5	35–6	36–7	37–8
Main stn. ..	Richmond River	Clarence River	Coff's Harbour	Port Macquarie	Port Stephens	Lake Macquarie	Lake Illawarra	Jervis Bay		

After this paper was written, statistics became available showing that three-quarters of the Queensland whiting catch comes from the three stations Gympie, Maryborough and Wynnum.

3. *Fishing Methods.*

A. *Methods using Mesh Nets.*

(i). *Working from Mud or Sand Flat.*—One fisherman holding one end of the net is landed on the flat, or in shallow water near the flat, while the other rows in an approximate circle and casts the net. The first man, carrying his end of the net with him, rejoins the boat. One of the ends is fixed to a rowlock and the net drawn in from the other end. One of the men beats the bottom with an oar to scare the fish, and thus cause them to enmesh themselves.

(ii). *Working with Sea Anchor.*—One end of the net is fastened to a basket which acts as an anchor. The method, in effect, dispenses with the first fisherman in method (i), but is otherwise the same. It is used in deeper water.

(iii). *Using Tide in Shallow Water.*—At high tide a stake is driven into the flat, and one end of the net tied to it; the net is then cast and the other end tied to the same stake. The net may be supported by stakes driven in along its circumference. Apparently wire netting is sometimes used in place of the net. When the tide goes down, the fish are collected from the meshes of the net or from the flat itself.

(iv). *Using Two Boats.*—In order to reduce the loss of fish due to disturbance of the water while casting, the net may be loaded equally on two boats, both of which cast. This reduces the casting time by half, and causes less disturbance of the water. Otherwise the method is similar to (i).

B. *Methods using Hauling Nets.*

Because they are necessarily of larger mesh, hauling nets are not really adapted for the capture of a fish of this shape; however, a considerable part of the landings is said to be made by this method. Kesteven (1942) has given a full account of the hauling nets and their methods of use.

The mesh nets of New South Wales must, by law, be not smaller than 2½″ in mesh, except in the Clarence River, where mesh nets of 2¼″ are allowed, and in Port Stephens, where nets must not be smaller than 1¾″ in mesh. The nets may be up to 50 fathoms long.

The boats used are the usual on-shore fishing boat, about 18 feet long. The value of the net is £10–20, and the boat about £50.

4. *Seasons of Fishing.*

The monthly landings in New South Wales show a maximum in summer and a minimum in winter, while in Queensland the maximum catches are made in late winter and early spring, as Table 4 indicates. The figures were arrived at by assuming an equal monthly catch and expressing the actual catch in each month as a percentage of this theoretical catch, thus making 100% equivalent to approximately 37,000 lb. of fish. The coefficient of variation of these data is approximately 15%. The cycle is thought to be due to increased gregariousness during the reproductive season.

TABLE 4.
Monthly Landings of Sand Whiting in New South Wales and Queensland.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
N.S.W.	126	113	114	100	99	88	88	78	66	97	120	104
Qld.	70	76	80	75	88	106	117	135	137	119	96	94

5. *Marketing.*

Marketing arrangements appear to be satisfactory, less than 0·5% of all fish being condemned in Sydney markets, and whiting does not make a disproportionate part of these.

6. *Existing Control.*

Methods used in the control of the fishery are:

(i). Fixation of the minimum legal length at 9½″ in New South Wales and 9″ in Queensland.

(ii). Fixation of net mesh as described above.

(iii). General method of closing certain waters to all or certain types of fishing.

IV. BIOLOGY.

1. *Raciation.*

As far as can be seen at present there is no conclusive evidence of raciation in these stocks. Whitley (1932) has granted to the Queensland specimens the rank of subspecies, but there appears to be no evidence to support this split, nor does Whitley appear to give any valid reason for making it.

The following characters were investigated on small samples of fish from each State.

A. *Morphological.*

(i). *Fin Ray Counts.*—No significant difference was found in the counts of the two diagnostic fins—the soft dorsal and the anal. The range was 17–19 rays and spines.

(ii). *Vertebrae.*—Twenty skeletons only were investigated. No difference was detected in these small numbers, counts of 33–34 being obtained. However, the numbers are too small to permit of a dogmatic statement.

(iii). *Scales.*—The scale count was made along the lateral line to the base of the caudal peduncle. The range 62–70 was found, but there was no significant difference between the two series.

It is doubtful if a difference in these characters could be called genetic as, according to recent work of Gabriel (1944), environment has a considerable effect.

(iv). *Body Proportions.*—Ten measurements were made on each fish, including length, breadth and height, but no significant differences were detected in the regression coefficients or the characteristics of Huxley's heterauxesis equation.

B. *Physiological.*

(i). *Spawning Time.*—There is a difference of three months in the spawning times of the Queensland and New South Wales fish. Whether or not this may be interpreted as evidence of physiological raciation depends on the physiology of the induction of spawning in this fish.

The induction of maturation and spawning in animals is thought to be governed by two main factors:

(1). Temperature, both as critical temperature and temperature change, which appears to be the factor in invertebrates and in some of the lower vertebrates. See Bullough (1939) and Moore (1942) for literature.

(2). Photoperiodism is the governing factor in most mammals, and it has been shown to be a factor in some fish. See Bullough (1939) and Marshall (1942) for literature.

The question now arises: can the difference of three months in the spawning time of the Queensland and New South Wales fish be shown to be due to either of these factors?

With regard to temperature, an inspection of the available surface isotherms of the two main fishing centres shows that a difference of 5° exists. This may or may not be sufficient to account for the observed difference in spawning time. If, indeed, temperature is the governing factor, the difference, by analogy with other cases investigated, may be sufficient.

When one plots the values for mean civil daylight for latitudes S. 25 and 32½ (Nautical Almanac) and compares the graphs planimetrically, the periods (*a*) from the end of spawning to the beginning of discernible maturation and (*b*) from the beginning of maturation to the spawning act show considerable differences in total daylight hours in the two States. Indeed similar calendar periods agree more closely than the biological periods delimited above, as Table 5 shows. The figures refer to planimetric figures only.

TABLE 5.

Period	Feb.-Aug.	Nov.-May.	Aug.-Jan.	Apr.-Sept.
N.S.W.	(*a*) 3,430	3,981	(*b*) 3,931	3,052
Qld.	3,527	(*a*) 3,905	3,802	(*b*) 3,376

A further complication was indicated by Bullough's (1939) work on the minnow. He showed that there was a critical temperature for the operation of the photoperiodic response, and this may explain the above unexpected results.

(ii). *Growth Rates.*—As Table 6 indicates, no significant difference between the growth rates of samples from the two States was found. The apparent significant difference in L2 is explained later.

TABLE 6.
Growth Rates in New South Wales and Queensland Samples.

	L1.	S.E.	L2.	S.E.	L3.	S.E.
Qld.	156	2·3	247	1·7	284·7	4·0
N.S.W.	159	3·1	241·6	1·3	285·7	2·7

It is difficult to give a satisfactory explanation of this equivalence. Knowledge of the effect of temperature on the growth of animals is still in an unsatisfactory state, but the records available indicate considerable complexity of the response.

The general finding that higher temperatures give smaller adults is not borne out here, neither does the acceleration of growth rate *per se* appear. See Belehradek (1936) and Fox (1939) for literature.

Two hypotheses are capable of explaining these data: (*a*) That the Fox effect is operating here, and that adaptation to higher temperatures has occurred. This would be no argument against homogeneity of stocks. (*b*) That there is a genetic adaptation to higher temperatures and that the similarity is an indication of some degree of raciation of the stocks.

(iii). *Ponderal Index.*—A difference approaching significance was found in the two sets of data, but the Queensland samples consisted of only 100 fish. The values of $k(\times 10^6)$ of the equation $W = kL^3$ were: Queensland 354 (S.E. 2·1), New South Wales 350 (S.E. 2·5).

While the possibility exists that raciation of a subtle kind may be present in the stocks, there is certainly no evidence for Whitley's subspeciation. For the purposes of the economic biology of the fish it has been concluded that the populations of New South Wales and Queensland may be considered to be from the same stock.

2. *Food.*

The small number of stomach contents examined showed only annelids and crustaceans. This, however, is in accord with fishermen's reports and the records of the earlier investigators. Tosh (1903) records much the same dietary for the Queensland fish.

3. *Reproduction.*

(i). *Gonad Maturation.*—In New South Wales, the fish begins to mature eggs for the next year's spawning in August–September. Most fish examined in September have pigmented ovaries and enlarging testes. The testes provide the most accurate index of the onset of maturation—they change from black, thread-like, to elongated, greyish, triangular bodies.

An attempt was made to follow this maturation by an arbitrary scale of gonad stages, but it was discarded as not being sufficiently accurate in the author's hands.

(ii). *Breeding Season.*—Since only five running ripe fish were taken during the present investigation, it is difficult to give accurate limits to the breeding season from direct sources.

A consideration of all data, both direct and indirect, led to the conclusion that the middle of the breeding season for the New South Wales populations was in January, with a total range of four months.

It is possible that the fish has two main spawnings in the year. One is led to this conclusion by the frequent trimodality of the ova-diameter frequency diagram—the modes representing: (*a*) immature non-maturing stock ova, (*b*) eggs of the second spawning, and (*c*) eggs of the first spawning. Furthermore, in large samples of first-year fish, the length frequency diagram often shows two modes. If true, the second spawning would follow closely on the first.

In Queensland, however, the mid-spawning time falls in September, with about the same range as the New South Wales season.

(iii). *Length at Sexual Maturity.*—The two-year-old fish definitely mature eggs and spawn, but the sexual maturity of the one-year-old fish is difficult to assess. The enquiry resolves itself into two aspects, (*a*) whether any eggs are matured and (*b*) whether any eggs matured are spawned and fertile.

Three types of ovary have been found in this first-year group:

(i). Glassy ovaries which show no sign of maturing eggs.

(ii). Pigmented ovaries with a few histologically normal eggs.

(iii). Pigmented ovaries showing usual numbers of histologically normal eggs.

Conditions (i) and (ii) greatly predominate.

The question of whether such eggs as are present are effectively spawned is more difficult to answer: they may be reabsorbed in the ovary, they may be spawned and infertile, or they may be completely fertile. By analogy with other cases of neotenic sexuality and adolescent sterility, the fish have been classified as adolescent and their contribution to the reproductive potential of the stocks is considered negligible. Even if this group were completely fertile and all normally fecund, assuming a constant relation between gonad weight and body weight, twice the number would be required to give a reproductive potential equal to that of two-year fish. This is important in considering control measures.

The second-year group is certainly mature and this puts the length (L.C.F.) at first maturity at about 260 mm.

(iv). *Spawning Place.*—It seems likely that spawning takes place either in the mouths of the rivers, etc., or more probably, in the open sea. This opinion is based on the following evidence: (i). Reports from various sources, official and otherwise, that in the breeding season large schools have been seen in the mouths of rivers making for the open sea. (ii). The occasional capture of whiting both by line and net on the ocean beaches in the neighbourhood of the natural habitat of the fish, and the visual identification of schools in the open sea. (iii). The infrequent appearance of ripe fish in the market catches. While this may be due to the very rapid terminal ripening of the eggs, it seems more likely to be due to the migration of the ripe fish from the fishing zone. (iv). The evidence brought forward in the previous section for the lack of clear-cut raciation implies some degree of genetic mixing, which could be accounted for by the larval and post-larval mixing which would occur with sea breeding.

(v). *Larval and Post-Larval Life.*—Tosh (1903) has described the egg, larva and embryo of this fish. The eggs are pelagic, and larval development takes one day at 26°C. After seven days at 22–23°C. the development of the gut is completed. According to the reports of New South Wales fishermen, schools of young whiting are seen along the shoreline in February and March. The post-larvae then migrate into deeper water and by June are no longer to be seen around the shoreline. Assuming that the eggs are subjected to the action of the Notonectian current, the times for development recorded by Tosh are adequate to give larval mixing over most of the coastline.

(vi). *Sex Ratio.*—The sex ratio differs significantly from the expected 50:50 ratio, being found to be 47·5 males to 52·5 females.

4. *Migrations.*

Fishermen seem to be in favour of the hypothesis that the fish migrate, but although the catch statistics at first seemed likely to give some information, no objective evidence on this problem was found.

5. *Ponderal Index.*

The relation between length and weight is adequately expressed by the equation $W = kL^3$. Weights were recorded in ounces and lengths in centimetres because of limitation of apparatus.

The characteristics of $k(\times 10^6)$ are indicated in Table 7. Dannevig (1903) has recorded data which agree fairly well with the present findings.

TABLE 7.
The Characteristics of $k(\times 10^6)$.

	Mean.	S.D.	S.E.	C.V.
Single sample	—	20	3·0	6%
Sample mean	350	6·8	2·5	2%

6. *Age Determination and Rate of Growth.*

(i). *The Scale.*—Cockerell (1915) has briefly described the scale of the sand whiting, but the following short description is included to indicate the method of scale reading.

The scale is approximately rectangular, but has the anterior ctenoid edge curved. Six to eight radii extend fanwise from the nucleus to the posterior edge and are roughly equally spaced. For purposes of description the scale may be divided into four triangles—two right-angled dorsal and ventral triangles (hereafter called lateral), one median isosceles triangle with the posterior edge as its base, and one small anterior isosceles triangle containing the ctenoid patch.

The nucleus is just above the midpoint of the base of the anterior triangle and is delimited by one or more circular circuli, and surrounded by more or less concentric subcircles, until these are transected by the radii. For the purposes of scale reading, the centre of the inner circle is taken as the growth origin.

The circuli of the median triangle are closely packed and transected by the radii, while the circuli of the lateral triangles are much less densely packed, communicating with about one in three of the median circuli. Changes in direction of these lateral circuli are here considered to be homologous with the ring of cycloid scales. The change is generally obvious and begins near the base of the lateral triangle, where two contiguous groups of circuli are seen to be at an angle to one another. As the apex of the lateral triangle is approached, the angle between the two groups is no longer visible. When the first circulus of the new direction group is followed round to the median triangle and the circuli of this region examined, one may find (*a*) no differentiation, (*b*) a bunching of the circuli of the region, as in the classical ring, or (*c*) granulation or branching of the circuli. In most cases some evidence of the change may be found in the corresponding area of the median triangle, and no difficulty was experienced in tracing the break around to the antero-posterior scale axis.

Scales for age determination were collected from just behind the posterior extremity of the pectoral fin; this region was found to give scales with the greatest ring definition. The scale was projected by the apparatus described by Kesteven and Proctor (1942). The first circulus of the new direction group was followed round to the antero-posterior projection axis, and the intermediate lengths read by the methods described by these authors.

(*a*). *Abnormalities.*—Abnormalities were fairly common, the following being found:

(i). Granulation of the nucleus. This was noticed especially in fish of over 300 mm. in length. Generally one ungranulated scale in the sample from the fish was found (about a dozen scales from each fish were taken), but if none could be found the position of the nucleus was estimated.

(ii). Absence of rings. This was a common abnormality. Usually only one was absent, and those present were in the usual positions and were recorded. Absence of all rings was a common feature of scales collected from positions other than the one recommended.

(iii). Reduplication of rings. This was a rare abnormality. When present, the scale was discarded.

(iv). Presence of ring in only one lateral triangle. A reading was nevertheless made since it was proved that the reading so obtained was compatible with readings of normal scales from the fish.

(v). Atypical break morphology. Considerable difficulty was experienced in reading the scales of fish more than three years old, because the breaks became atypical. The method is suitable only for fish of less than four years.

(*b*). *Validity of Intermediate Lengths read from Scales.*—The validity of the scale method has been shown by a large number of authors, and it is probably reasonable to assume that the method is valid in every case. However, it is desirable to give verification in special cases, especially of tropical and sub-tropical fish. In this investigation the following methods were used:

A. *Establishing Precision.*

(i). Reproducibility in individual fish. Successive scales from the selected area were read, and the calculated intermediate lengths were found to agree. The coefficient of variation was 2·85%.

(ii). Reproducibility in single samples of fish. When a single sample of fish was examined the calculated intermediate lengths were found to agree within themselves and to be groupable on a normal frequency curve. The calculated intermediate length for one-year fish could sometimes be shown to follow a bimodal frequency distribution, a result of the twice a year spawning. The coefficient of variation declines from 13% in the first year to 6% in the second.

(iii). Reproducibility between samples of fish. There is good agreement between mean calculated intermediate lengths of samples after the first year. The coefficient of variation declines from 6% in the first year to 2% in the second.

B. *Establishing Accuracy.*

(i). Agreement with length-frequency data. The length-frequency diagrams of samples taken in the season when the ring is laid down correspond to the frequency curves of the calculated intermediate lengths. This is shown in the arithmetic seasonal growth curve (Fig. 2).

(ii). Agreement from year to year. Scales taken over a period of four years give substantially the same calculated intermediate lengths, and there appears to be no appreciable change of growth rate from year to year. For example, the growth of the fish spawned in 1940 and 1941, as calculated from the scales, was 161 and 158 mm., respectively. The pooled S.E. was 2·45 and the difference was not significant. The figures for these two years represent the greater part of the scale reading data.

(iii). Agreement with mathematical theory. The data obtained fall on a smooth curve, and when plotted semi-logarithmically, all points but the first and second fall on a straight line. The reason for the ectopy of the first two points will be discussed later.

(*c*). *Time of Ring Formation.*—The age in months was calculated by determining the month in which the rings were laid down. This was done by plotting the percentage of rings laid down in the various months. Considerable difficulty was experienced in diagnosing a newly laid down ring and consequently the middle part of the curve had to be interpolated rather subjectively. This led to the hypothesis that by October, 50% of the rings had been laid down. Nothing has since been found to invalidate this hypothesis.

Thus the age in months corresponding to the consecutive rings is 10, 22, 34, 46, etc. The ring on the scales from Queensland fish was found to be laid down three months before that of the New South Wales fish and the ages corresponding to the rings are thus the same for both States. The ring may be laid down to a response to improving food conditions or as a response to the beginning of sexual maturation; the latter hypothesis seems the more likely, as it would account for the conditions in both States.

(i). *Rate of Growth in Length.*—As determined by scale reading, this is shown in Figure 1 with both arithmetic and logarithmic plotting. Figure 2 shows the seasonality of growth. It was constructed by including all data of scale reading and mean lengths of samples, and so represents the mean growth of the fish month by month.

In the logarithmic graph the first and second points do not fall on the straight line. Point 1 is so because it represents growth over the biologically poorest months of the year. The length reached after a full year of growth, as read from the seasonal graph, is 220 mm., and assuming constant growth rate through the year, the length reached in ten months would be 183 mm. This point falls much more closely on the line. The

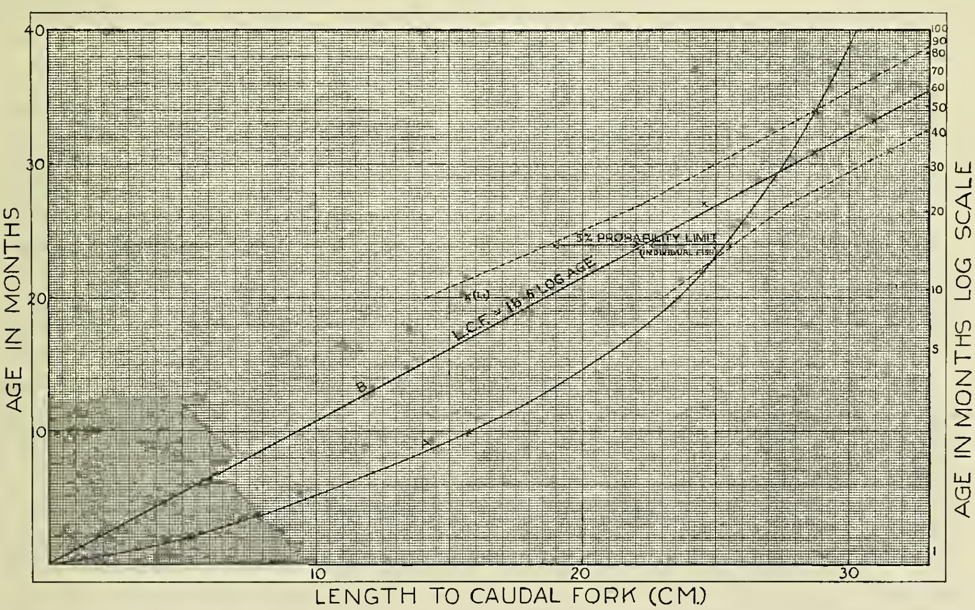

Fig. 1.—Rate of growth in length. Curve A shows arithmetic plotting and curve B shows logarithmic plotting. Scale data only.

second point is atypical because many of the New South Wales samples used for scale reading were collected in the months when the rings were being laid down, and so only the lower intermediate lengths are represented. This bias also appears in Figure 4. It was also noted in the section on raciation.

The rate of growth in length is adequately expressed by the equation $Y = ab^x$, where Y is the age in months, x is the L.C.F. in mm., and a and b are constants.

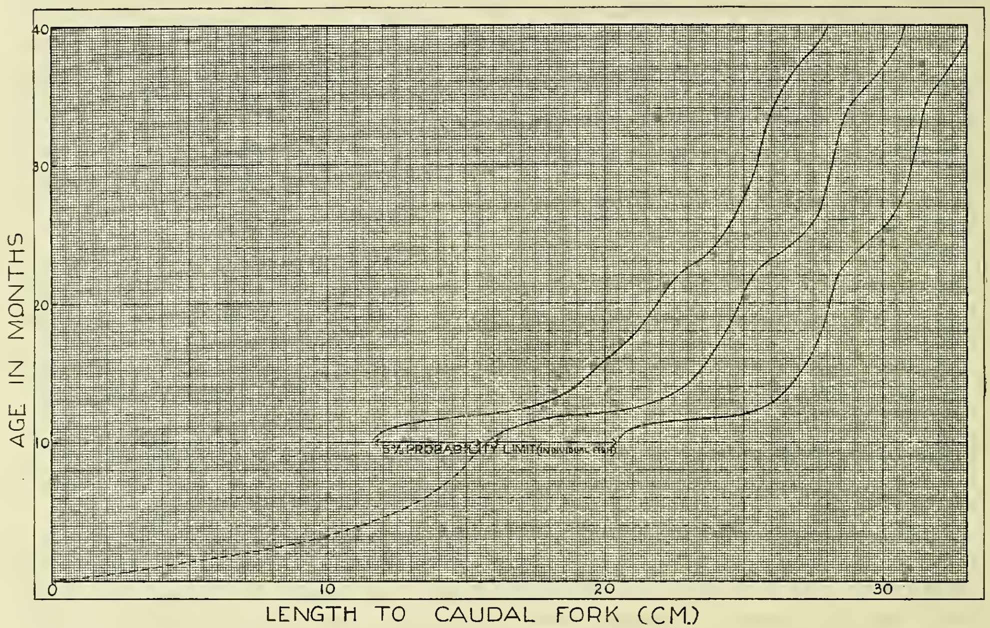

Fig. 2.—Showing the growth of the fish for each month of life. The curves were constructed (*a*) from the scale data and (*b*) from the mean lengths of about 70 samples of fish of one age group taken in various months of the year. Samples often contained only one age group and no difficulty was experienced in separating age groups when more than one was present.

No useful purpose would be served by recording all the scale data, but these data, both for Queensland and New South Wales, are summarized adequately in Table 8.

TABLE 8.
Summary of Scale Data.

	L1.	S.D.	S.E.	C.V.	L2.	S.D.	S.E.	C.V.	L3.	S.D.	S.E.	C.V.	L4.	S.E.
Single sample ..	—	22	4	13%	—	14	4	6%	—	14	4·5	5%	—	3
Sample mean ..	158	10·5	3	6·7%	244	5	1·5	2%	285	6·8	3	2·5%	312	1·5

The largest New South Wales specimen obtained in the present investigation had a length of 430 mm. and an estimated age of 18 years. The largest Queensland specimen was 450 mm. long and its age was estimated as 22 years by the equation for rate of growth in length.

(ii). *Rate of Growth in Weight.*—Figure 3 shows the rate of growth in weight. The following equation fits the data: $X = K \frac{(\log. Y - \log. a)^3}{(\log. b)^3}$ where X is the weight in ounces, Y the age in months, a and b are the constants in the length-growth equation, and K the ponderal index. It will be seen that the growth is approximately arithmetic for the first three years in life.

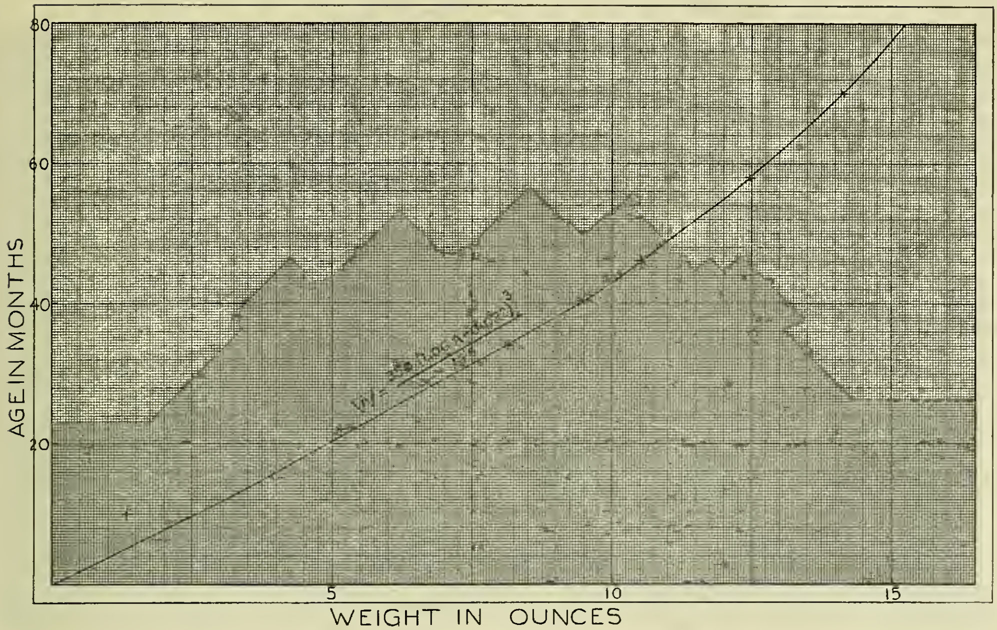

Fig. 3.—Rate of growth in weight.

7. *Pathology.*

The sand whiting has few parasites, either external or internal. Occasional worm parasites and neoplasms have been seen, but the only condition of economic importance is known to fishermen as "tarriness".

In this disease the fish is permeated by a peculiar tarry odour and taste which make it unfit for human consumption. The condition is apparently sporadic and not very common. Since no tarry whiting appeared during the time the author was in the markets no further description of the condition can be given.

V. Condition of the Fishery.

1. *Economic Evidence.*

Catch statistics, except for two records in 1892 and 1893, which cannot be incorporated, exist for the period from 1938 onwards for New South Wales and from 1936 onwards for Queensland. It is impossible to trace trends over such a short period. Since most of the fisheries of Australia show some evidence of depletion (Kesteven, unpublished data), it seems likely that this fishery would also show economic evidence of this type also.

Fishermen are not inclined to express a definite opinion on this point, but there appears to be a suspicion that the fishing is not as good as it was. Fluctuations in a small fishery like this, especially long term ones, are not likely to impress fishermen until a state of serious depletion exists.

2. *Biological Evidence.*

New South Wales market measurements were available for a period of four years. Figure 4 is a frequency diagram of these data.

Queensland market measurements were available in small numbers for the period 1943–44. The numbers are only just on 3,000, but the sampling has been adequate. The frequency diagram is shown in Figure 4. In this figure the Queensland numbers have been multiplied by three to make the curves more directly comparable.

The minimum legal total lengths for both States and the desirable minimum legal length are also shown in Figure 4. The percentages of the fish below these various lengths are shown in Table 9.

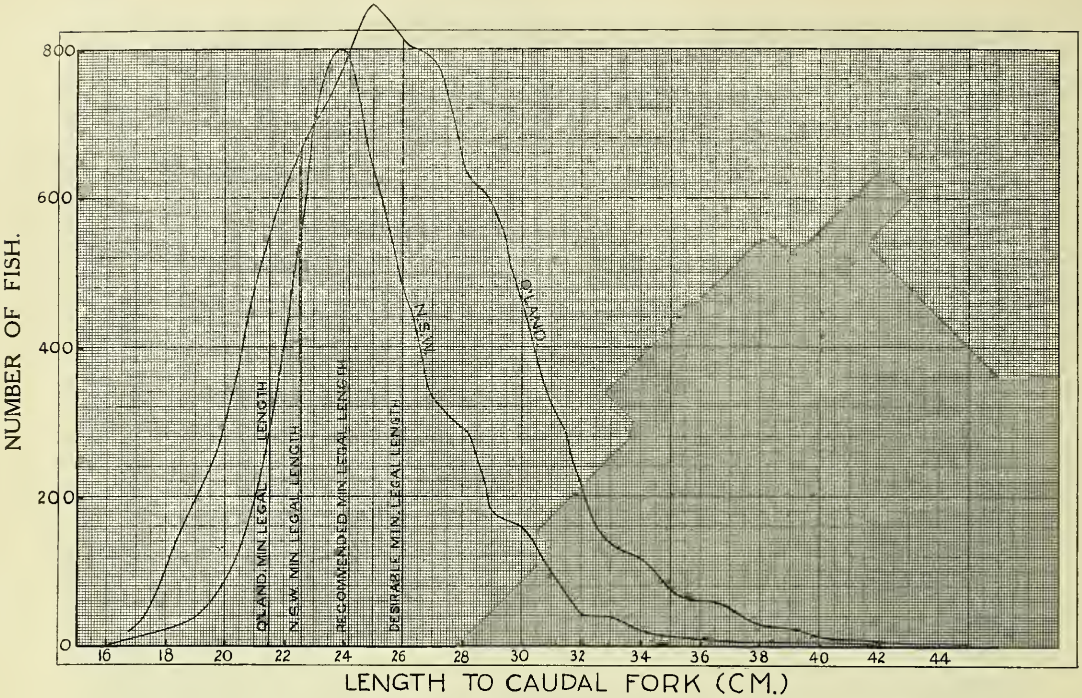

Fig. 4.—Frequency curves of the lengths of fish reaching Sydney and Brisbane markets. The Queensland figures have been multiplied by three to make the curves more readily comparable.

TABLE 9.

Percentages of Fish below Minimum Legal Length.

		N.S.W.	Qld.
Below Qld. minimum	9″	7·8%	13·0%
Below N.S.W. minimum	9½″	17·6%	20·9%
Below ideal minimum	10¾″	68·6%	42·7%
Below recommended	10¼″	56·3%	52·9%

VI. Suggestions for Control.

The following methods of control are suggested; their feasibility must be judged by those in administrative control of the fishery.

1. *Minimum Legal Length.*

It has been demonstrated that the existing minimum legal lengths are too low to protect the immature fish. A minimum legal total length of 275 mm. (10¾″) would be more in accord with biological fact, but an increase of 1¼″ would almost certainly be tolerated by fishermen; for this reason a minimum legal length of 10¼″ is recommended. This would not be subject to decrease even if conditions improve, and would, of course, apply in both States. It is interesting to note that Dannevig (1903) suggested 10¼″ as the minimum marketable size of this fish.

2. *Regulation of Net Mesh.*

No further change in the existing New South Wales regulations would be required except to make them apply to the whole State. Netting experiments have shown that the 2¼″ mesh is very destructive not only of immature whiting but also of other commercially important fish. It will enmesh fish at least as small as those shown in Table 10 and, of course, fish corresponding in shape to those recorded.

This control of net mesh would apply in both States and would not be liable to change if conditions improved.

TABLE 10.

Fish Enmeshed in Nets of 2¼″ Mesh.

Species.	L.C.F. (mm.).
Fantail mullet (*Mugil argenteus*)	200
Tano mullet (*Myxus elongatus*)	200
Sand whiting (*Sillago ciliata*)	180
Tarwhine (*Roughleia tarwhine*)	110
Silver Biddy (*Gerres ovatus*)	110
Herring (*Harengula castlenaui*)	120

The season when catches are greatest is also the time when the immature whiting becomes capable of capture by this net.

These suggestions for control would, if implemented, cause a fall in both numbers and weight of whiting caught, but in a year or two, while the numbers would be less, it is probable that the total weight landed would be considerably more than at present.

VII. SUMMARY.

(i). The landings of sand whiting in New South Wales and Queensland are approximately equal and are in the region of 500,000 lb. each per year and are valued at £25,000 in each State.

(ii). The taxonomic literature is listed and a simple key is appended.

(iii). In the area bounded by latitude S. 31 and latitude S. 34 the landings are greatest, but the fish is distributed along the entire coastline of New South Wales.

(iv). Mesh nets are most used for the capture of this fish, and the various ways of using them are listed.

(v). Maximum landings occur in summer in New South Wales and in early spring in Queensland.

(vi). There is no definite evidence of raciation in the stocks.

(vii). Food consists of the annelids and crustaceans of the mud and sand flats.

(viii). The breeding season for the New South Wales fish is from November to March and for the Queensland fish from July to November. Two spawnings may occur in this period.

(ix). The L.C.F. at first sexual maturity is 260 mm.

(x). Spawning is thought to occur in the open sea.

(xi). The sex ratio is 47·5 males to 52·5 females.

(xii). No evidence of migration was found, but was thought to occur.

(xiii). The weight-length relation is expressed by the equation $W = 350L^3 \times 10^{-6}$, where W is the weight in oz. and L is the L.C.F. in mm.

(xiv). The scale and method of scale reading is described. A verification is made for the method.

(xv). Half the fish have breaks in the circuli by October.

(xvi). The rate of growth in length is expressed by the equation L = 186 log. A where L is the L.C.F. in mm. and A is the age in months.

(xvii). The rate of growth in weight is expressed by the equation $W = 350\frac{(\log. A - 0{\cdot}028)^3}{146}$ where W is the weight in oz. and A the age in months.

(xviii). A large proportion of the market catches both in New South Wales and Queensland is made up of fish which have not yet spawned.

(xix). Recommended control methods are the raising of the minimum legal length to 10¾″ and the prohibition of mesh nets of less than 2½″ mesh, both provisions to hold in both States.

VIII. Acknowledgements.

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